The isovector effective charge and the staggering of the $2^+ \rightarrow 0^+$ transition probabilities in the Titanium isotopes

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In an effort to understand the magical status of N=32 and N=34 at the very neutron rich edge, experiments have been carried out in the Titanium isotopes up to A=56. The measured staggering of the B(E2)'s is not reproduced by the shell model calculations using the best effective interactions. We argue that this may be related to the choice of the isovector effective charge and to the value of the N=34 neutron gap.

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The two-body nucleon-nucleon interaction is different in the two isospin channels T=0 and T=1. Consequently, the mean field that it produces varies depending on the relative number of neutrons and protons in a nucleus. At and around the stability line we find the conventional "magic" numbers that, in the independent particle model of Mayer and Jensen [1], were obtained by the addition of a strongly attractive spin-orbit potential to the isotropic harmonic oscillator. Approaching the proton drip line, these magic numbers seem to persist. The neutron drip line lies farther away of the stability valley, hence, the weight of the T=1 channel of the nuclear interaction relative to the T=0 channel increases in the mean field. One could wonder which would be the magic numbers of the multi-neutron mean field, provided such a mean field made sense. One thing is clear; they will not coincide with the standard ones.

In the shell model context, this situation can be approached adding only neutrons -but many- to a well established doubly magic nucleus. In this case, the T=1 monopole interaction among the valence neutrons modifies the initial mean field felt by a single neutron on top of the doubly magic core. The important point to notice is that the eventual modifications of the shell structure should be due solely to the T=1 nucleon-nucleon interaction. One could rephrase that by saying that the magic numbers for extremely neutron rich nuclei are dictated by the neutron-neutron interaction. The addition of valence protons activates the T=0 neutron-proton channel, leading to the recovery of the known magic numbers. See in this respect the controversy in [2, 3] on the monopole drift of the magic closures.

A very handy study case is provided by the Calcium isotopes, that are nowadays known up to N=34. A strong sub-shell closure was shown to exist at N=32 some time ago [4]. The persistence of this sub-shell closure upon addition of protons has been the object of many experimental studies recently [5]. As there is no spectroscopic information available on ^{54}Ca, less neutron rich, N=34, isotones have been explored [6] in order to check the magical status of N=34. As a by-product of these studies, Dinca, Janssens *et al.* [7] have made a comparison of the experimental excitation energies of the lowest 2^+ states and the $2^+ \rightarrow 0^+$ transition probabilities in the even Titanium isotopes and the predictions from the full pf shell model calculations using the newly build effective interaction GXPF1 [8]. This interaction produces a large subshell gap at N=34, that disagrees with the experimental results [9]. An even newer interaction, GXPF1A [10], has been produced that predicts a less pronounced N=34 gap. However, none of them can explain the staggering of the experimental B(E2)'s (see Fig. 2 in [7] and Fig. 1). This comes out as a surprise, the more so noticing that the interaction KB3G [11], that does not predict a noticeable N=34 gap, is also unable to reproduce the trend of the data, even if, precisely at N=34's ^{56}Ti, it behaves better, as can be seen in Fig. 1.

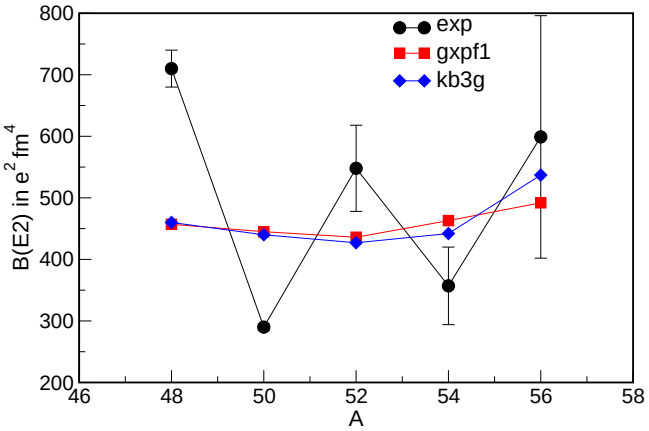

FIG. 1: Theoretical B(E2)'s in the Titanium isotopes, calculated with effective charges q_π=1.5 e and q_ν=0.5 e, compared with the experimental results

Although there is general agreement on the use of an isoscalar effective charge of +1.0 e in this region, the situation is less well established for the isovector effective charge. The calculations discussed above take it equal to zero, while Dufour and Zuker [12] obtain +0.2 e and a very recent experimental and shell-model analysis of the E2 transitions in the mirror pair ^{51}Fe-^{51}Mn [13], using the interaction KB3G, concludes that the isovector ef-

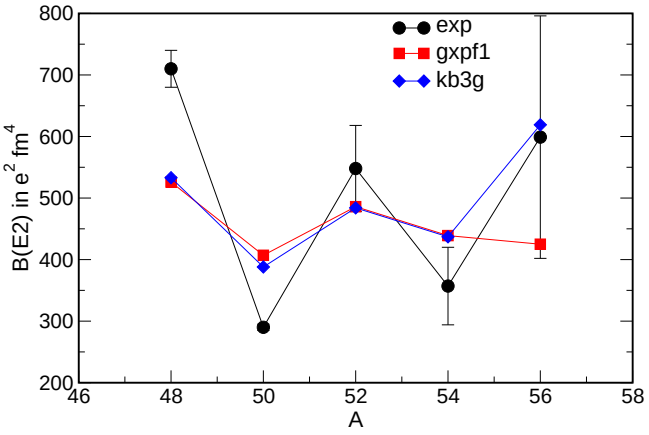

FIG. 2: Theoretical B(E2)'s in the Titanium isotopes, calculated with effective charges q_π=1.15 e and q_ν=0.8 e, compared with the experimental results

fective charge is much larger; +0.65 e. Dinca, Janssens *et al.* [7] mention this new set of effective charges but they conclude that "although these values would induce a small staggering in the calculated B(E2) values, they are not sufficient to bring experiment and theory into agreement". However, a more detailed analysis turns out to be worthwhile. In Fig. 2 we show the results using the new effective charges. The comparison of Fig. 1 and Fig. 2 is very telling. The results with KB3G and GXPF1 are identical for ^{48}Ti, ^{50}Ti, ^{52}Ti, and ^{54}Ti, irrespective of the set of effective charges used. Besides, using the new values of the effective charges, the experimental trend – and even the experimental values– are now much better reproduced. Why is it so? Because a larger neutron effective charge tends to amplify the contribution of the neutrons to the transition. If this contribution is large, *i. e.* in absence of shell closure, it can override the effect of the reduction of the proton effective charge. If the neutrons are closed, the effect goes in the opposite direction. And this is what is seen in Fig. 2: in ^{48}Ti, N=26, the B(E2) goes up, in ^{50}Ti, N=28, down, in ^{50}Ti, N=30, up and finally, in ^{54}Ti, N=32, down. The staggering is ready, and N=28 and N=32 reaffirm their sub-shell status.

We have deliberately left ^{56}Ti apart, because here, using the new isovector effective charge, the results of the two calculations diverge, reflecting their different underlying wave functions, in turn dictated by their very different N=34 gaps. Consistently with the discussion above, the new effective charges reduce the B(E2) value of GXPF1 because it closes the neutrons at N=34. On the contrary, they enhance the KB3G value that does not have such a closure.

In summary, the puzzling disagreement between theory and experiment in the lowest transitions of the Titanium isotopes can shed unexpected light into two apparently disconnected topics: The N=34 sub-shell closure far from stability and the value of the isovector effective charge for E2 transitions.

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